The detection of single electrons using the MediPix2/Micromegas assembly as direct pixel segmented anode

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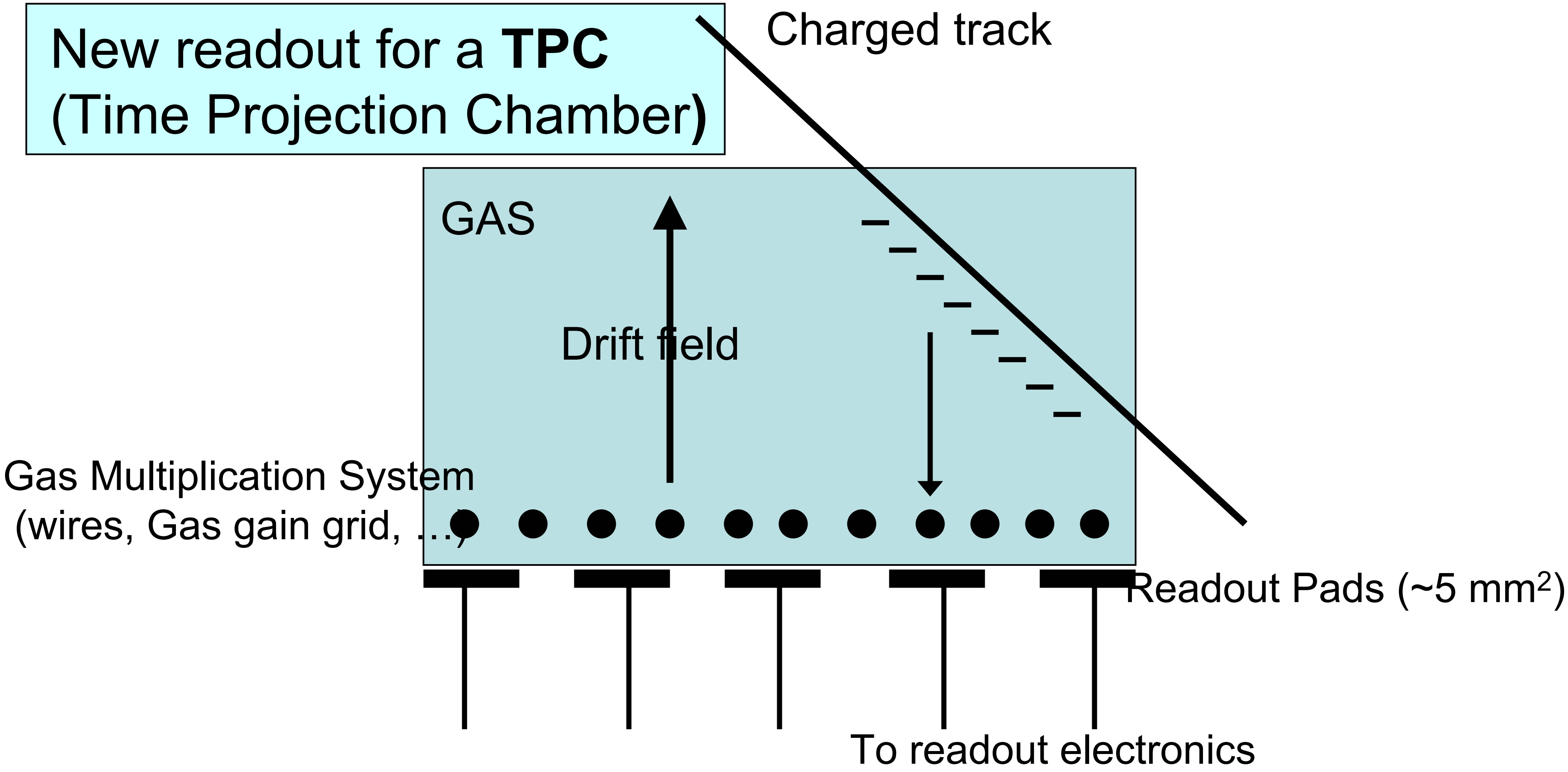
Goal



2D pads + drift time = **3D** information about track

→ Very interesting for **high energy physics** experiments

Goal (2)

OUR GOAL:

- pads (5 mm^2) → CMOS pixel chip (100 μm x 100 μm)
- integrate gas gain grid on the CMOS pixel chip (wafer post processing)
- future Linear Collider (or LHC upgrade? Or Babar/Belle?)

MANY ADVANTAGES:

- **Simpler to build:** gas gain grid, pads, readout circuitry → **1 single element**
- **Better resolution**
- **Single electron detection:** dE/dx measurements, δ-ray suppression
- Large number of readout channels, small pixel size → **very low hit occupancy**

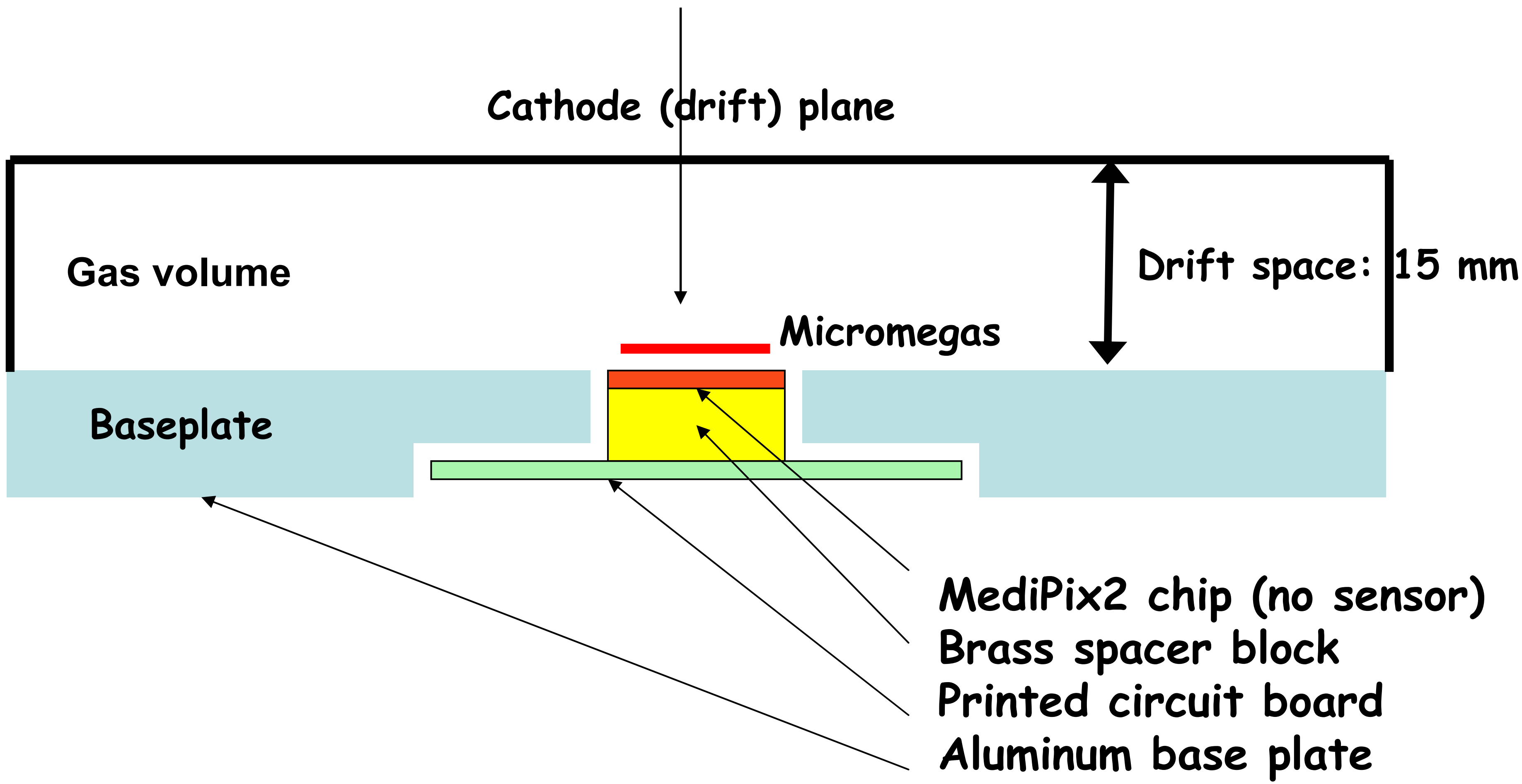
→ Proof-of-principle with the Medipix2 chip

The Medipix2 chip

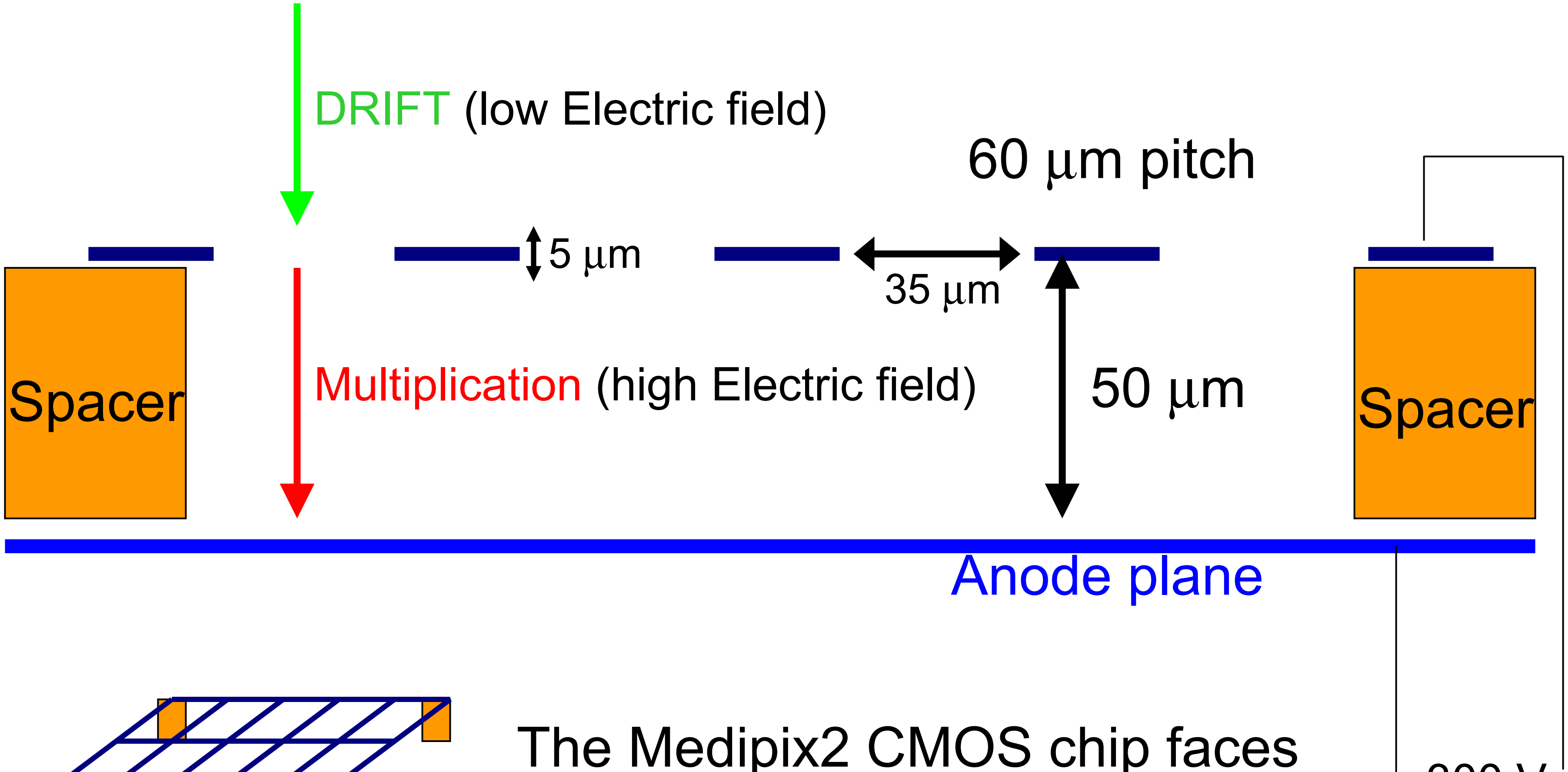
- A CMOS chip in .25 µm technology for X-ray imaging
- Usually bump-bonded to a semiconductor X-ray sensor
- 256 x 256 pixels, area = 1.4 x 1.4 cm^2
- Pixel size: 55 µm x 55 µm
- Positive or negative input charge (e^- or holes collection)
- 13-bit counter per pixel
- Count rates of 1 MHz/pixel (0.33 GHz/mm^2)

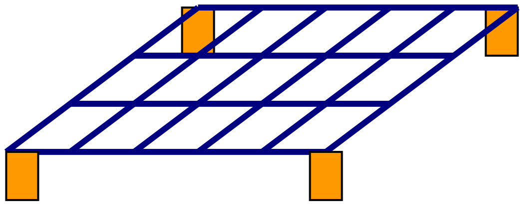
Goals: X-ray imaging for many applications (medical, material analysis, synchrotron applications, etc.)

Micromegas/Medipix2 prototype TPC: setup



Micromegas/MPix2 prototype TPC: setup(2)

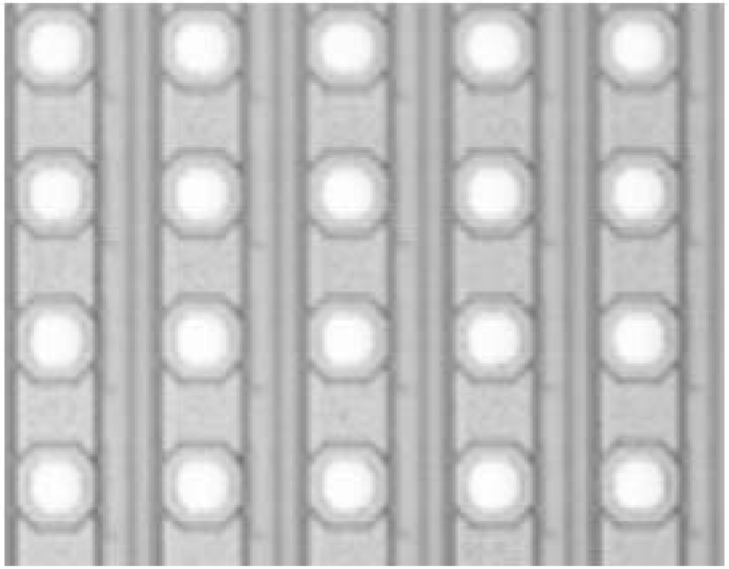




The Medipix2 CMOS chip faces an electric field of 350 V/50 μm

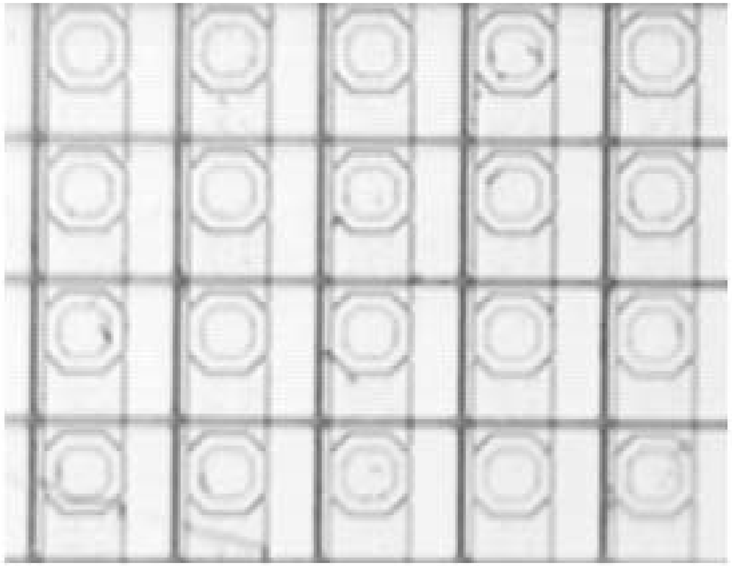
= **7 kV/mm !!**

Micromegas/MPix2 prototype TPC: setup(3)



a)

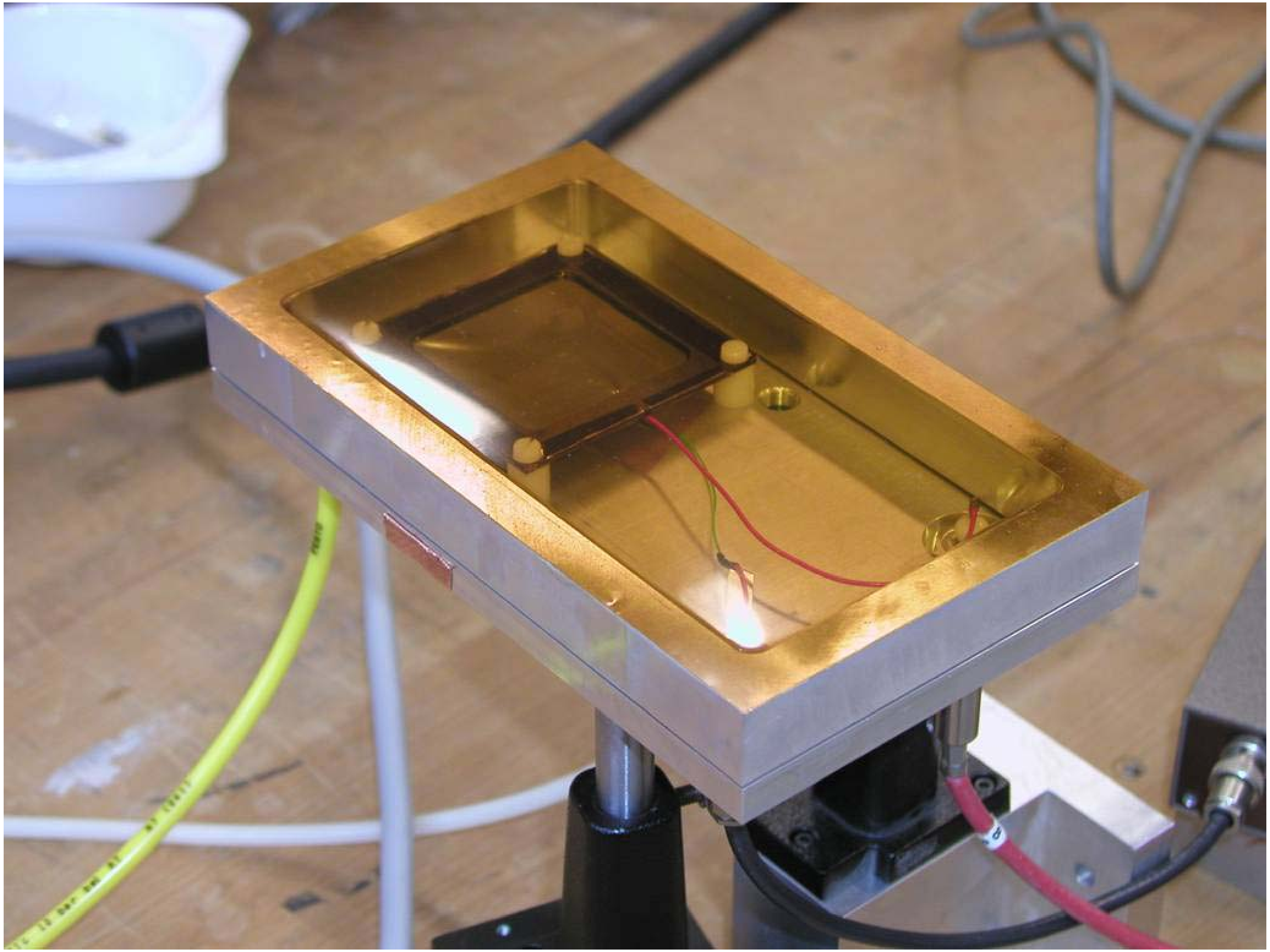
Standard Medipix2 chip
~20% metallized surface
~80% insulator



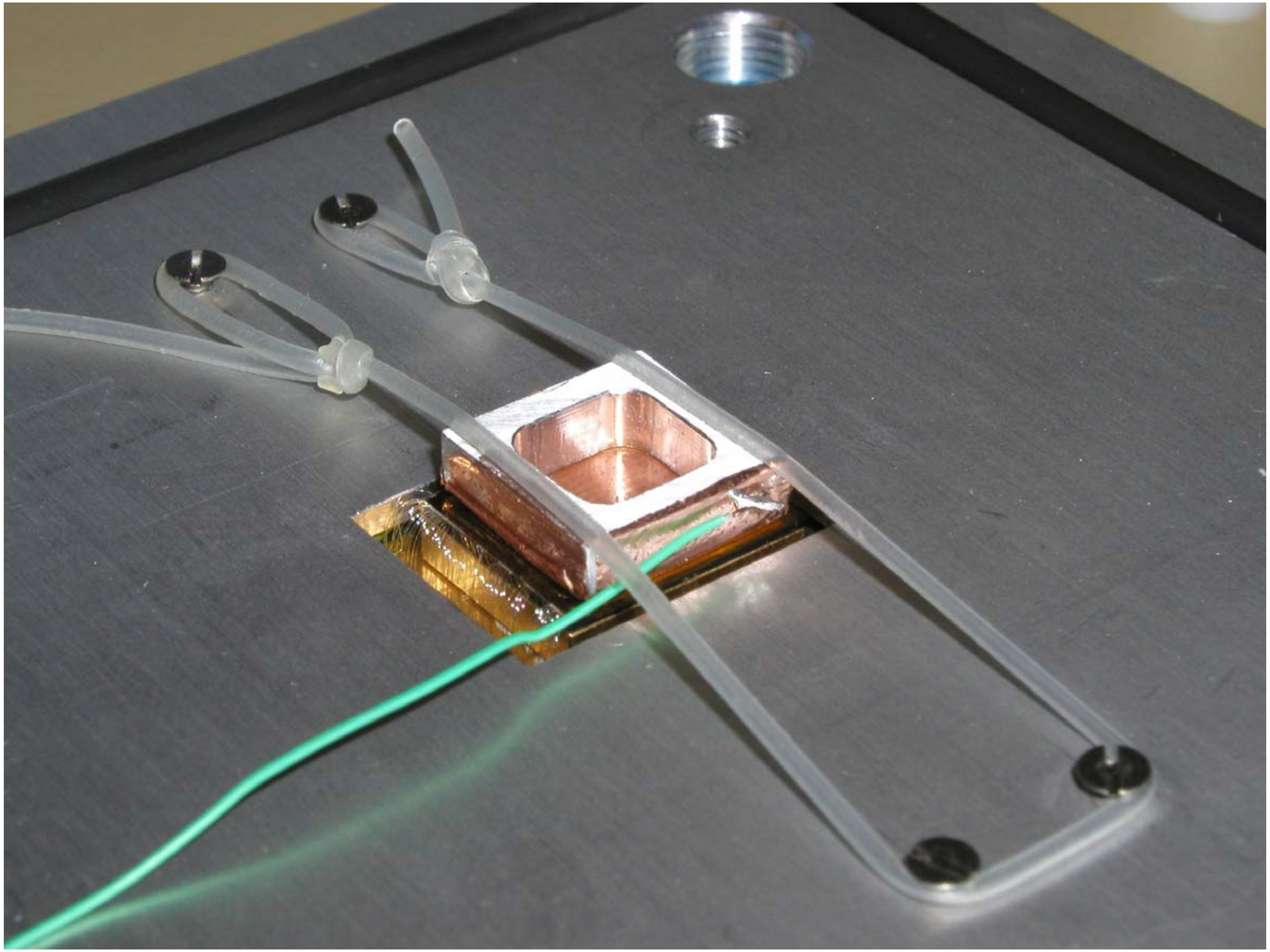
b)

Modified Medipix2 chip
(lift-off post-processing,
Univ. Twente /MESA+)
~80% metallized surface,
~20% insulator
45 x 45 μm^2 sens. pixels

Micromegas-equipped TPC: setup (4)



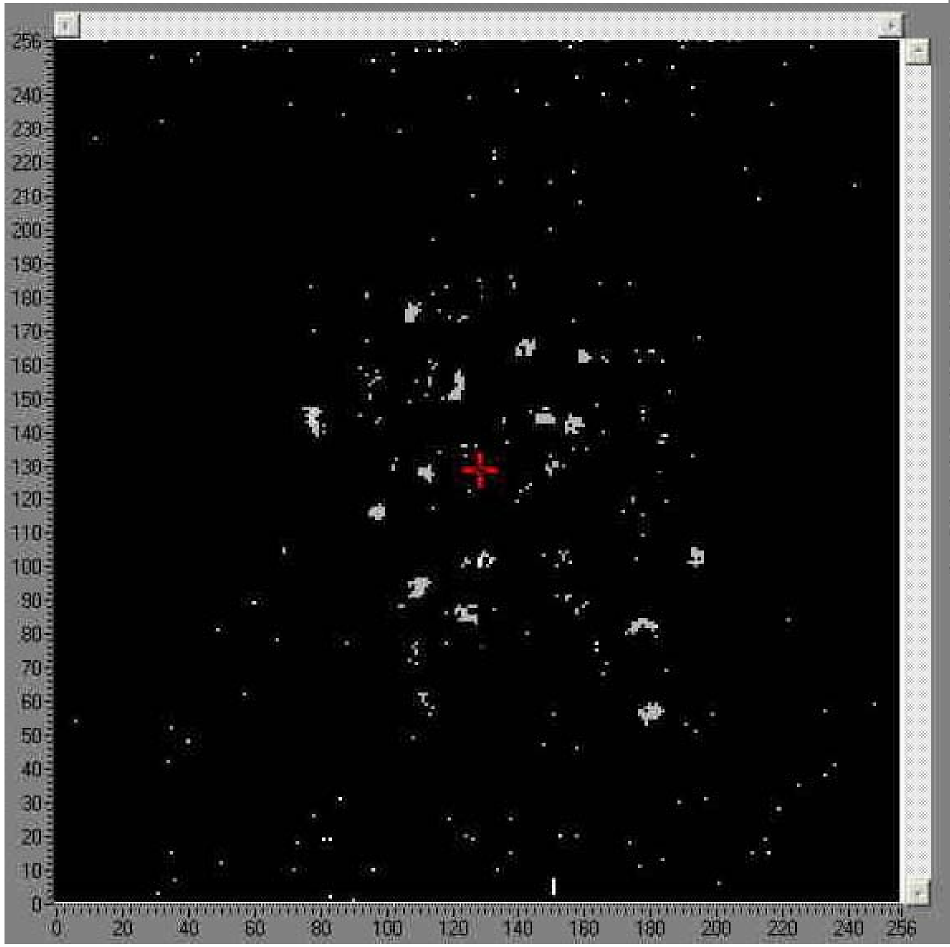
Micromegas-equipped TPC: setup (5)



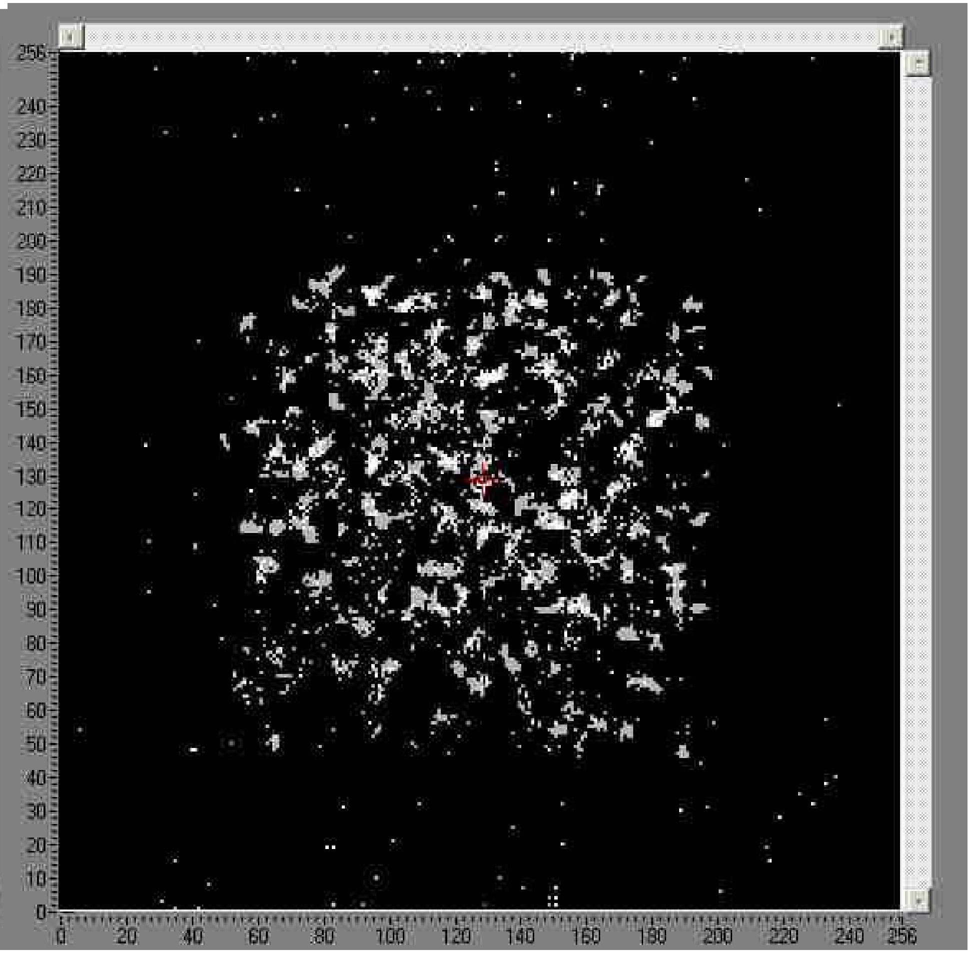
Micromegas-equipped TPC: results

Metallized Mpix2

Ar 95 /Isob, 5 (February 2004)



^{55}Fe, 1s



^{55}Fe, 10s

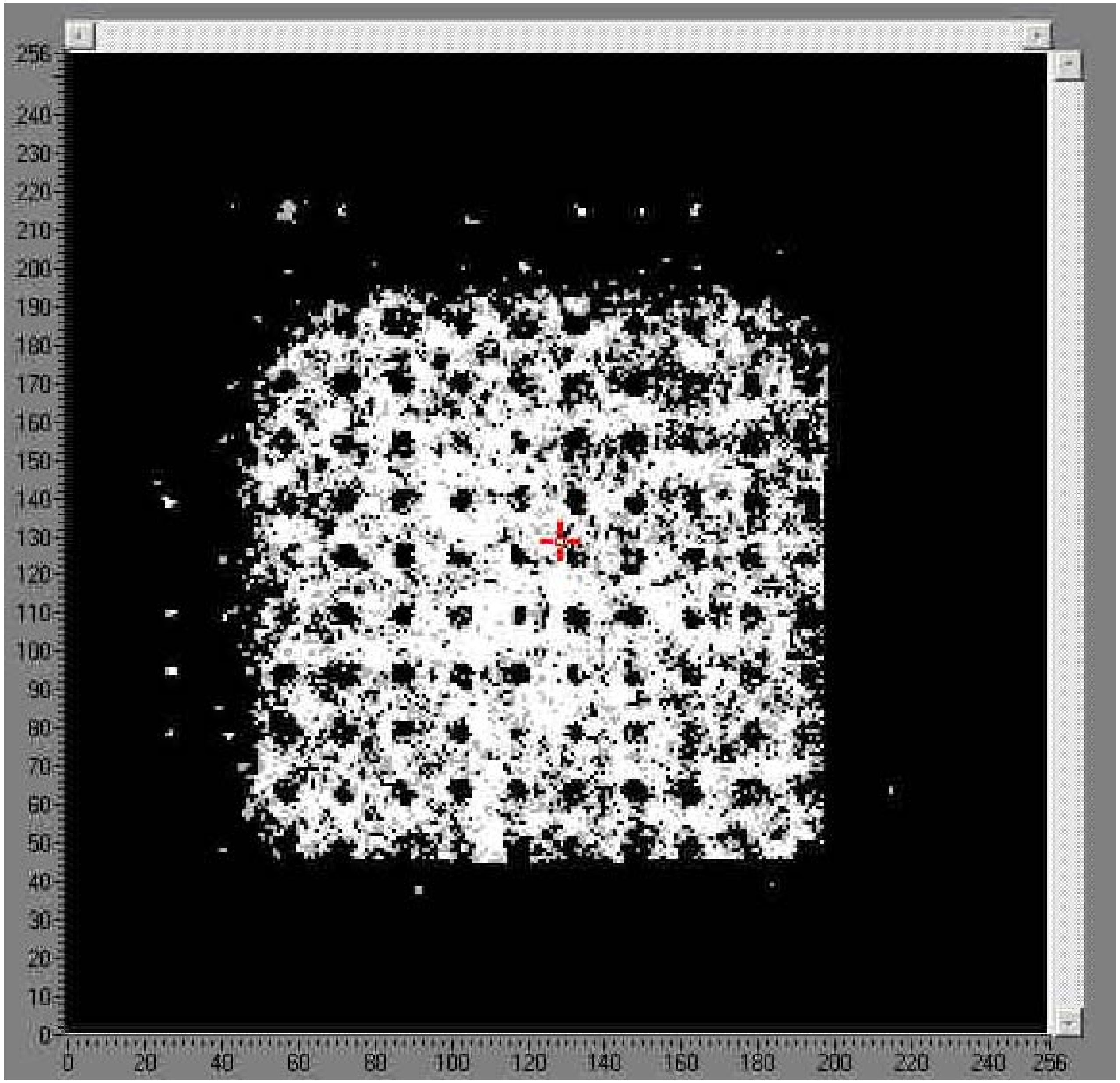
Micromegas-equipped TPC: results (2)

(February 2004)

Metallized Mpix2

Ar 95 /Isob, 5

^{90}Sr, 1s



(March-April '04)

Metallized Mpix2

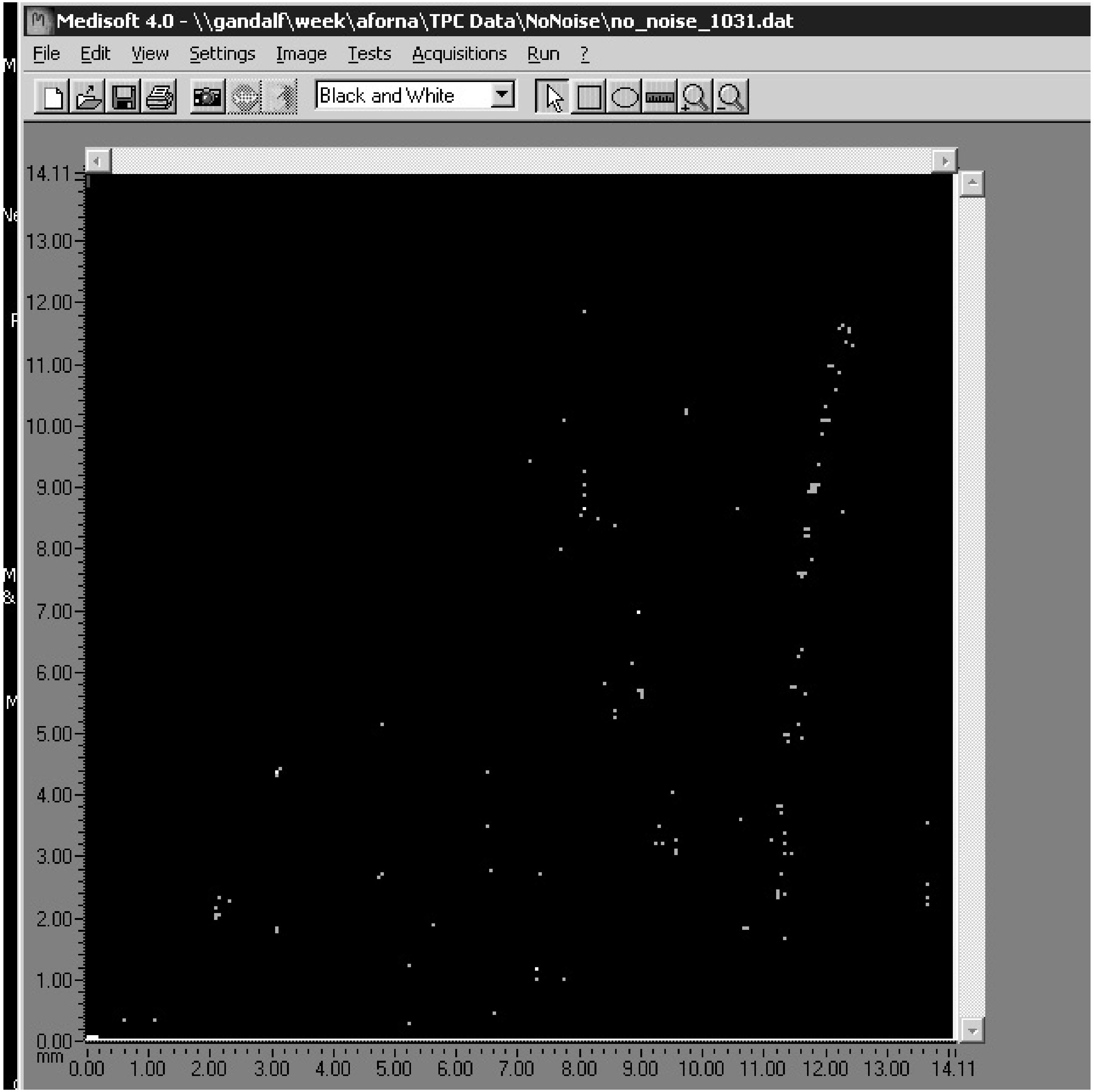
He80 Isob. 20
(G=5000-10000)

No rad. source

15 sec exposure

(NO TRIGGER!)

→ Cosmic track



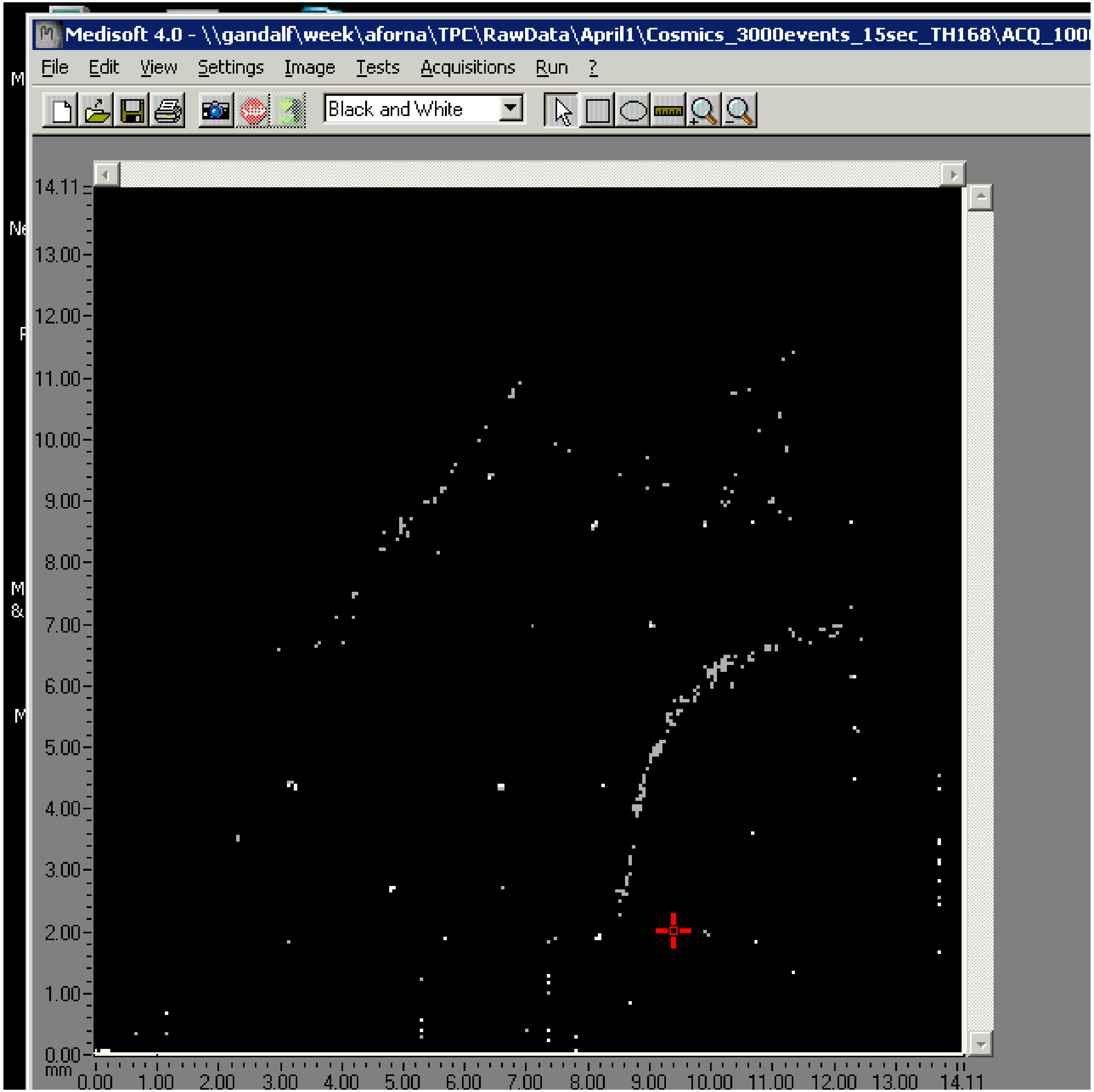
(March-April '04)

Metallized Mpix2

He80 Isob. 80
(G=5000-10000)

No rad. source

15 sec exposure



→ **Cosmic track**

12

(March-April ‘04)

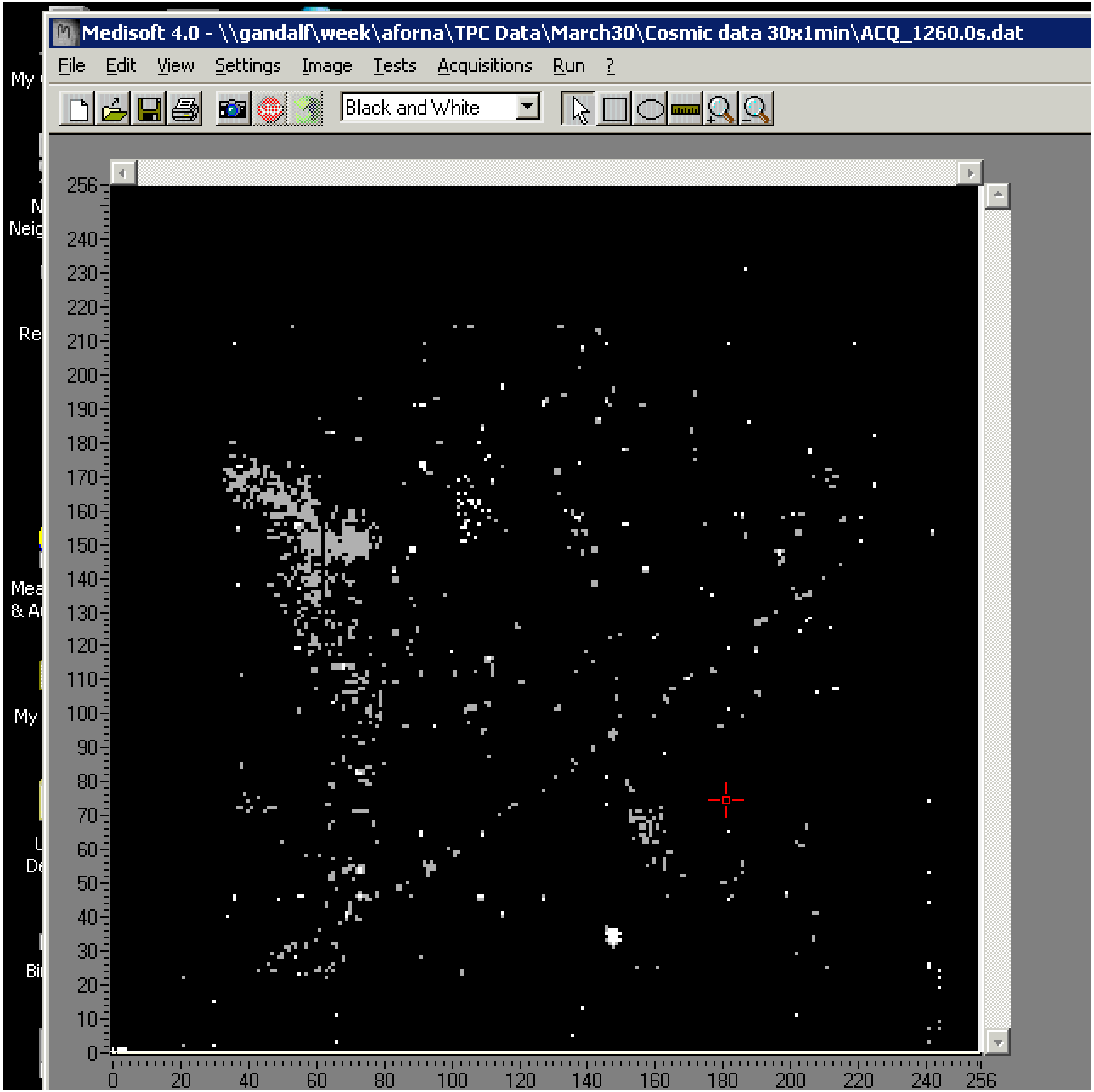
Metallized Mpix2

He80 Isob. 80
(G=5000-10000)

No rad. source

60 sec. exposure

→ **Cosmic track**



(March-April '04)

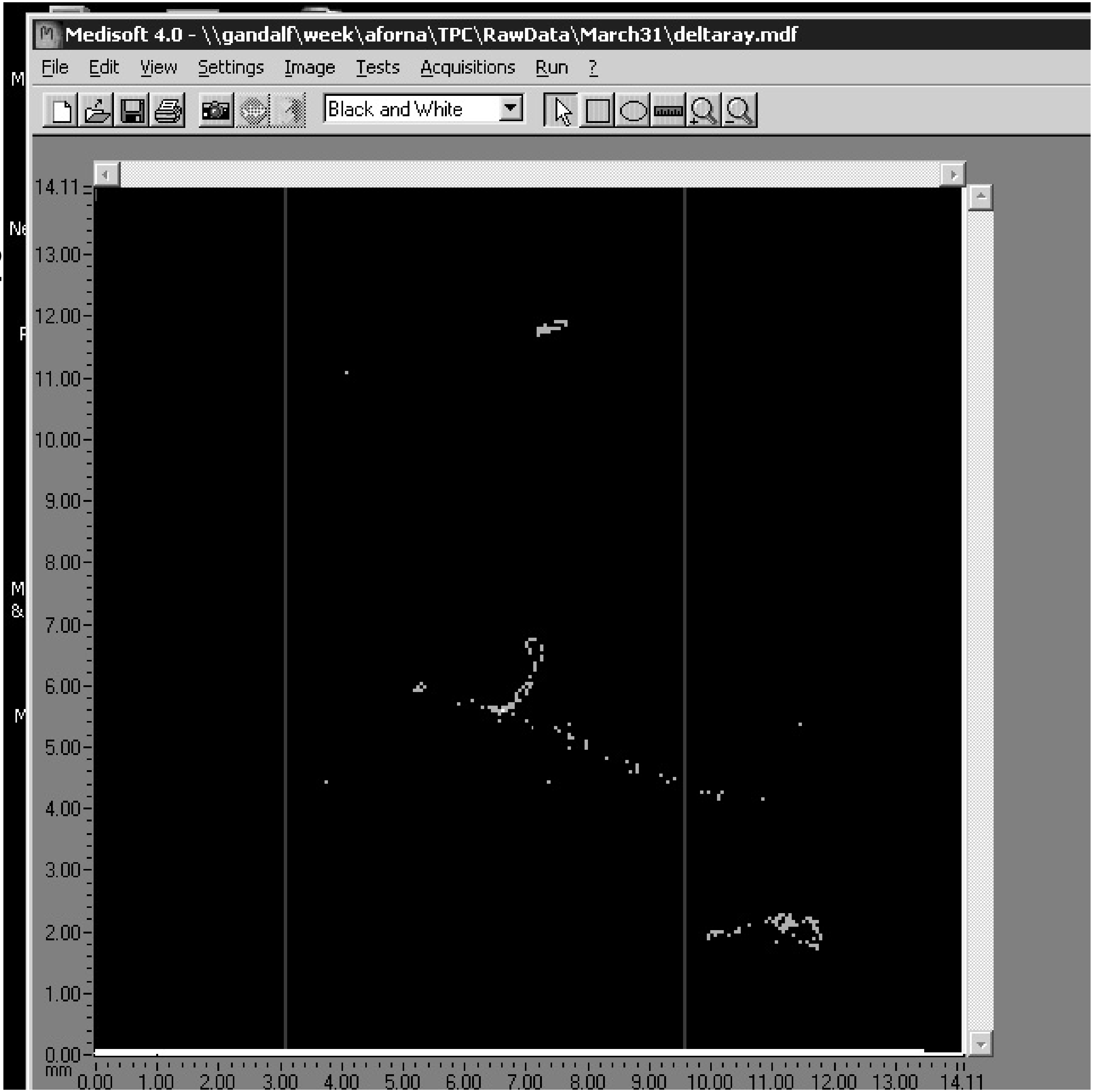
Metallized Mpix2

He80 Isob. 80
(G=5000-10000)

No rad. Source

1 sec exposure

δ-ray!



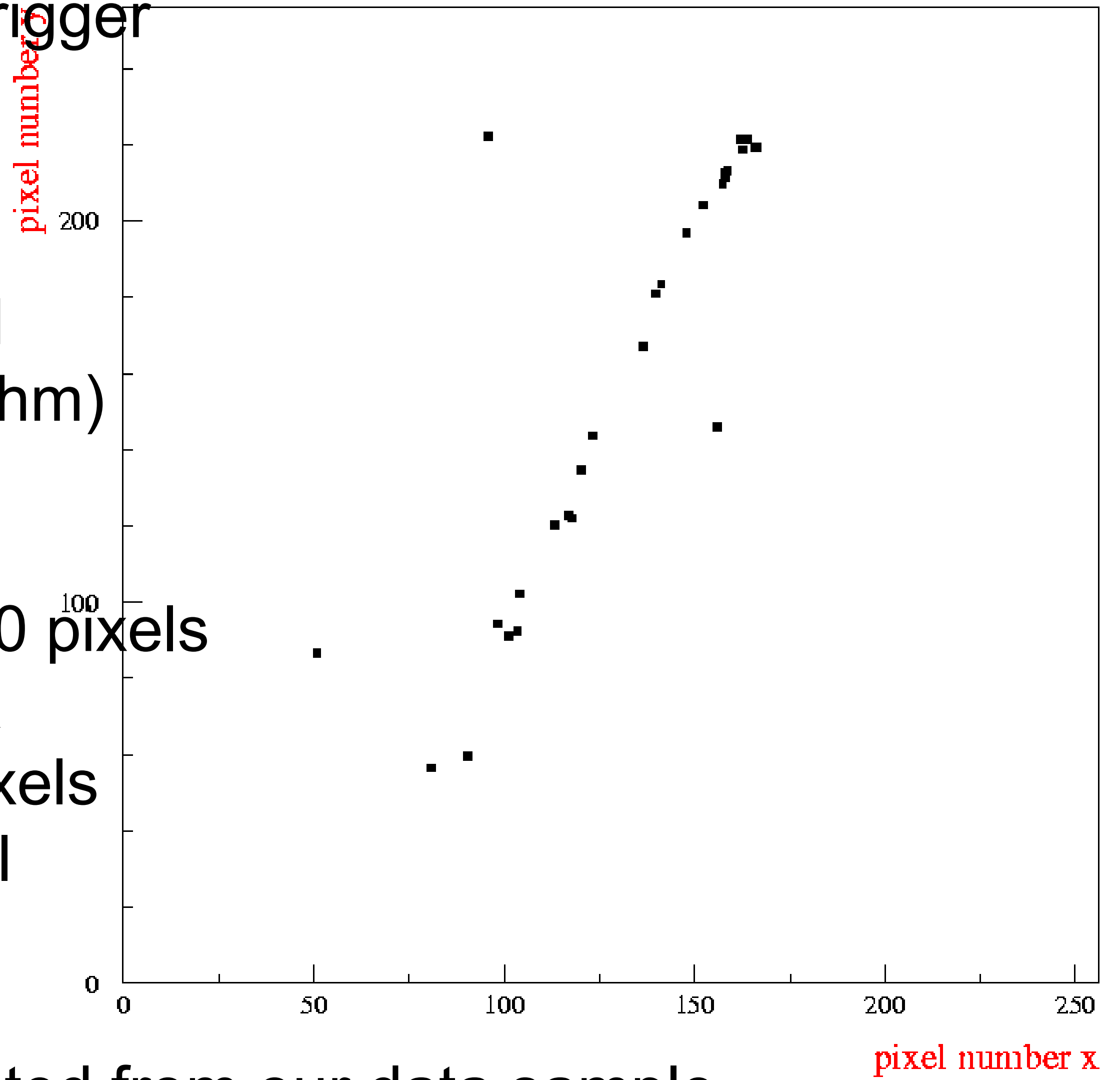
Primary electrons detection

- Data set: 6000 cosmics images, 10-15 sec. acq. time, no trigger

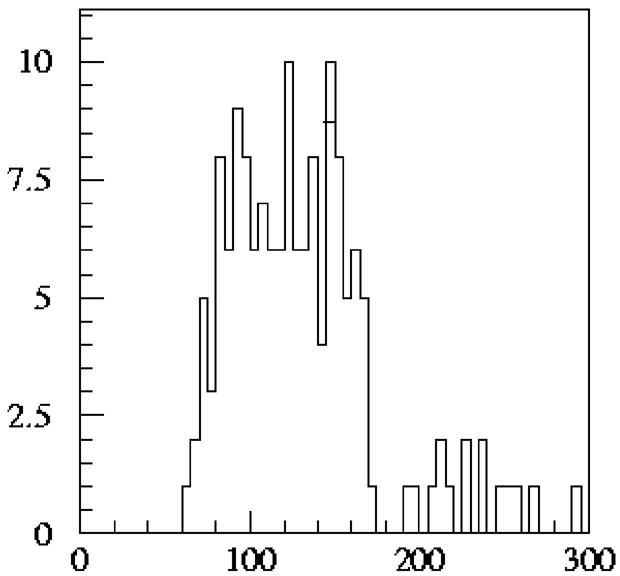
- Noisy pixels eliminated

- Events with MIP selected (pattern recognition algorithm)

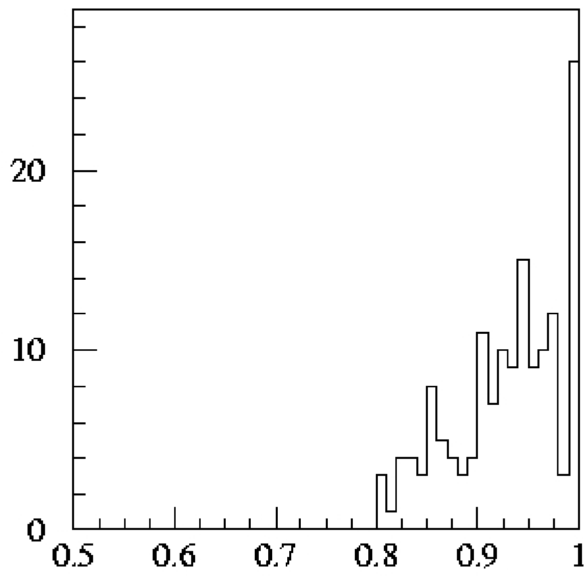
- Cuts applied
    - track xy projection> 50 pixels
    - more than 5 hits/track
    - transverse rms < 4 pixels
    - associated pixels/total pixels hit > 80%



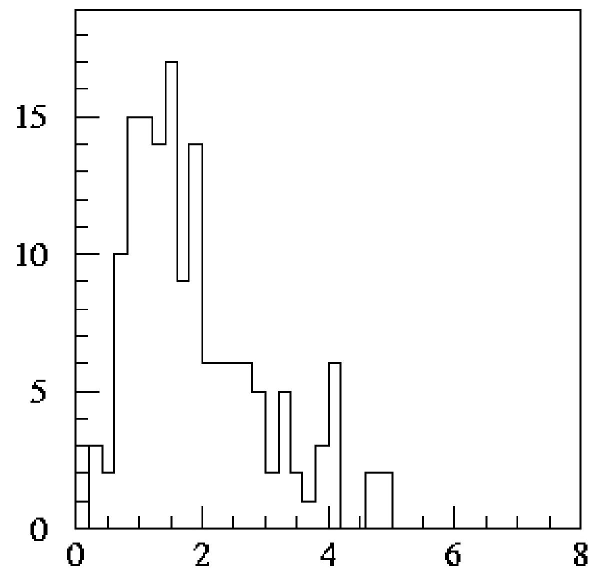
164 tracks selected from our data sample



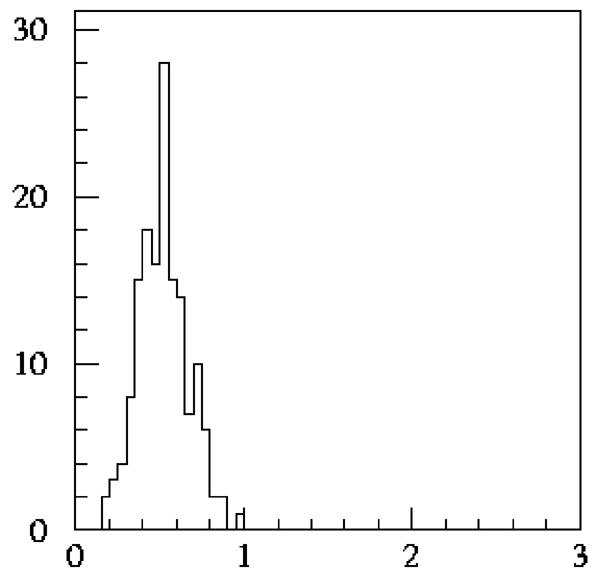
Projected lengths (pixels)



Fitted e- per mm



Fitted e- per mm



Fitted clusters per mm

Efficiency for single electrons

For each 3D track L:

- count number of charge clusters C associated with the track

- C/L → detected primary electrons/unit length, $N_{measured}$

- primary electrons released by a MIP/unit length: $N_{expected}$ (from literature)

$$\varepsilon = N_{measured}/N_{expected} > 90\%$$

with He-based gas mixtures (He/isobuthane 80/20)

Single electrons detection efficiency

Efficiency: gas gain and pixel threshold

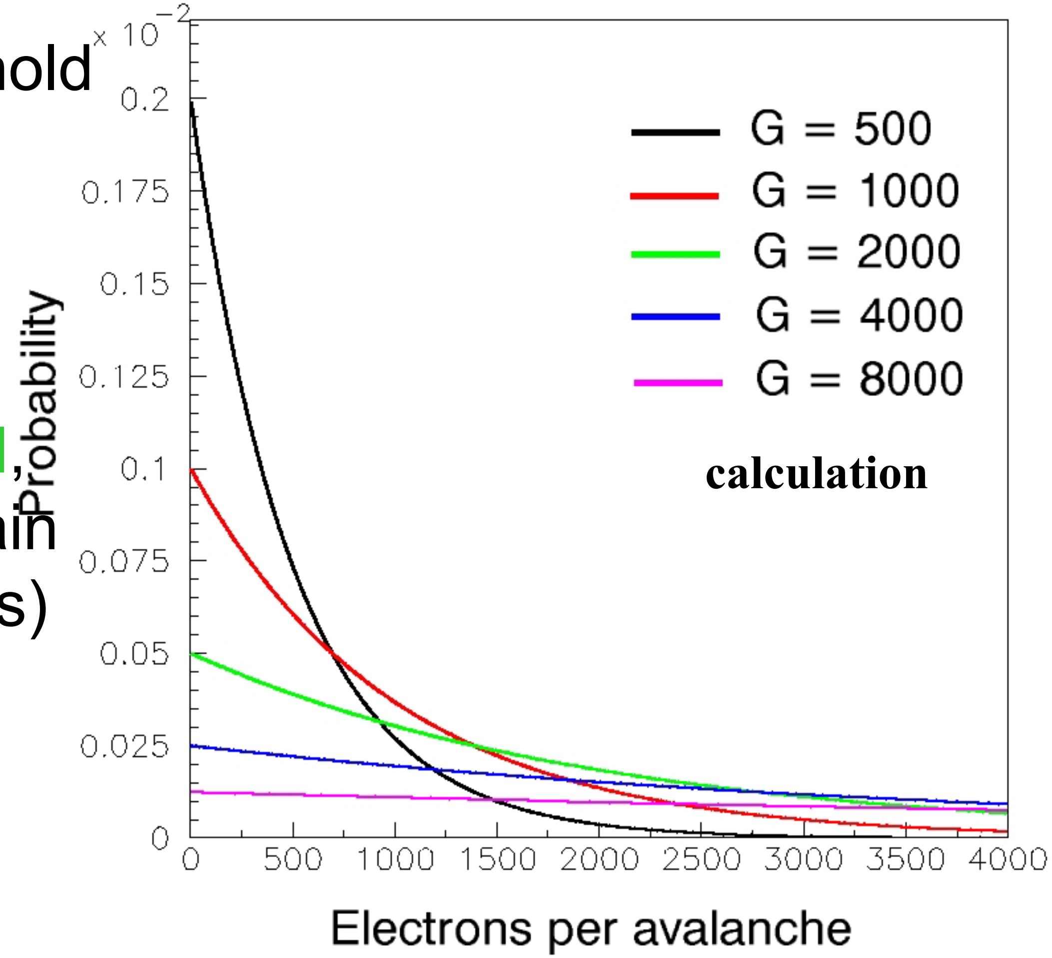
ε depends on the Mpix2 threshold and gas gain

Working point: THR = 3000 e-

High efficiency: low threshold, high gain **but** a not too high gain is preferable (risk of discharges)

→ so a low threshold is even more important

To reach higher gains, very high voltages were applied → several MPix2 were damaged



$$p_{Aval.}(n) = 1/G \exp(-n/G)$$

$$p_{thr.}(n) = \int_{THR}^{Inf.} 1/G \exp(-n/G)$$

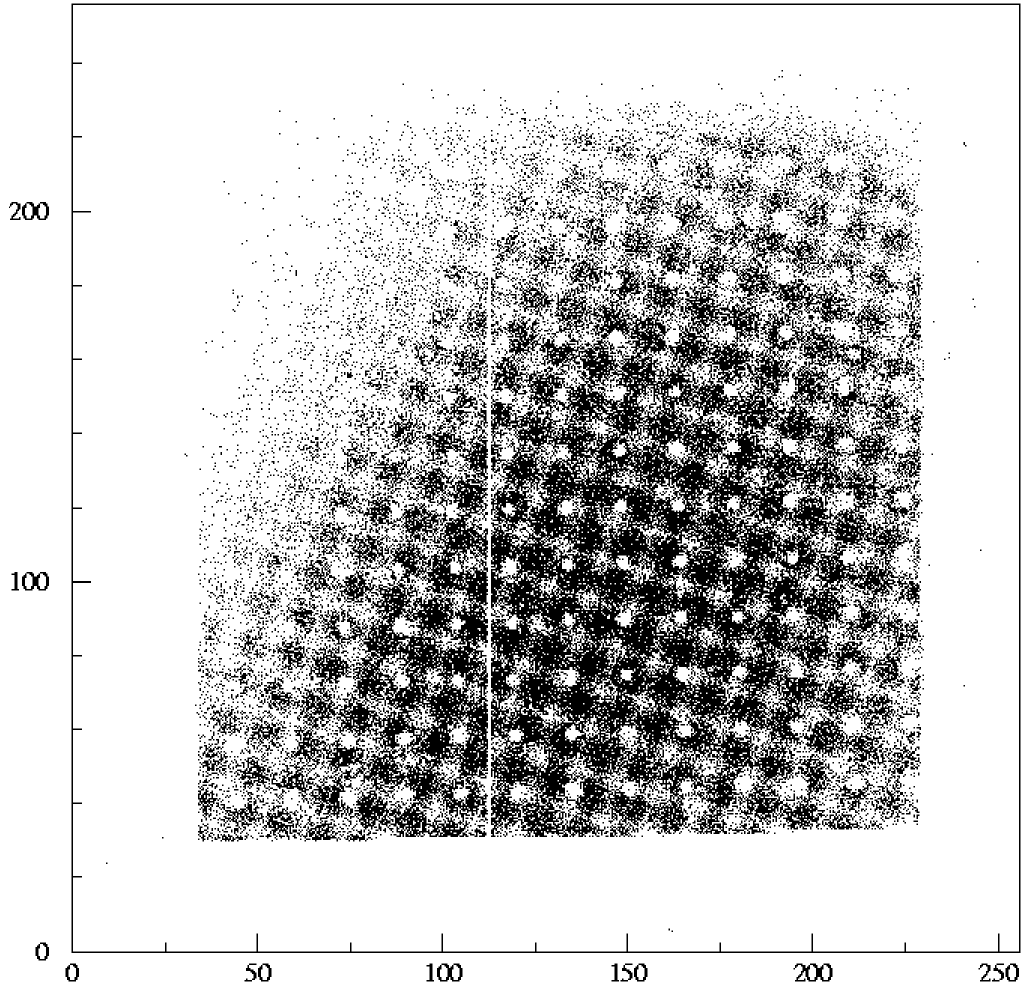
The Moire' effect

- Bands of lower efficiency

- Two perpendicular directions

- Periodicity of **12 pixels**

- Effect less pronounced in metallized MPix2 chips



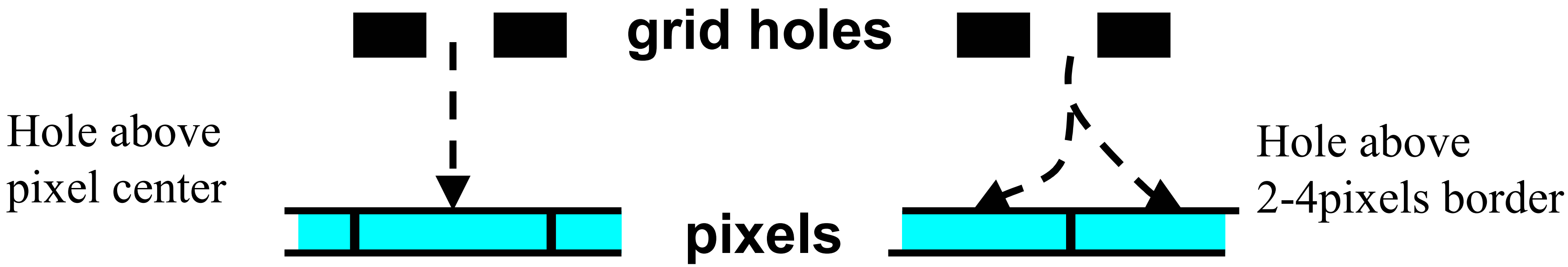
(image taken with ^{90}Sr source)

The Moire' effect (2)

Micromegas: 35 μm diam. holes, **60 μm pitch**
Medipix2: 55 μm X 55 μm pixels, **55 μm pitch** → **mismatch!**

Hole position above the pixel shifts along a column or row

Repetition every **60/(60-55) = 12 pixels**
→ matches the periodicity of the inefficiency bands



1) e- pulled to a pixel further away, E field weaker → less multiplication
+ **2)** charge splits in 2 adjacent pixels

SOLUTION: integration of gas gain grid on the CMOS chip

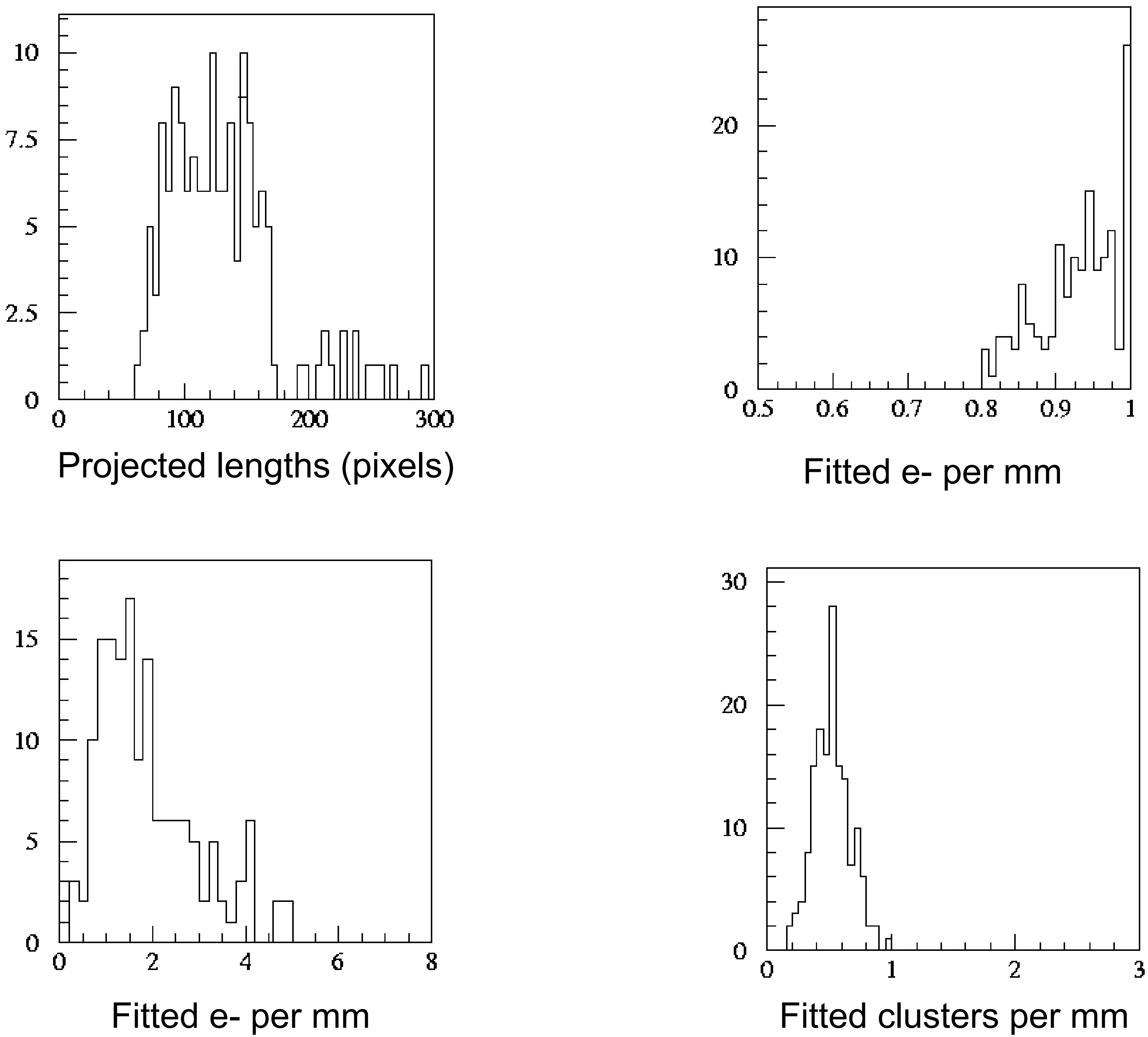
Conclusions and future plans

- Proof-of principle using Medipix2 was successful: a CMOS pixel chip can detect electrons in a gas multiplication system!

Short term goals: data analysis and simulation

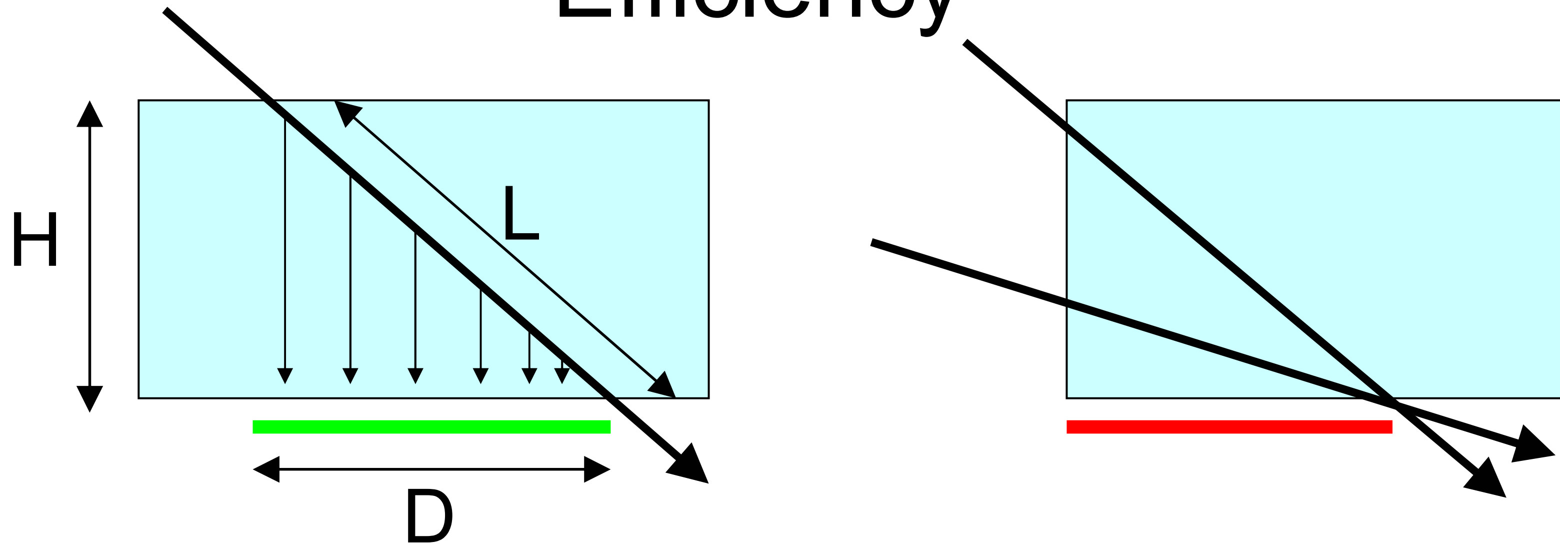
Medium term goals: add a cosmic rays triggering system (scintillators), beam test at CERN (*e*-, π, μ…)

Long term goals: design of a new TimePix pixel CMOS chip for use in a TPC environment, integration of the gas gain grid (Micromegas) on the MPix2 (and then TimePix) by means of wafer post-processing technology.

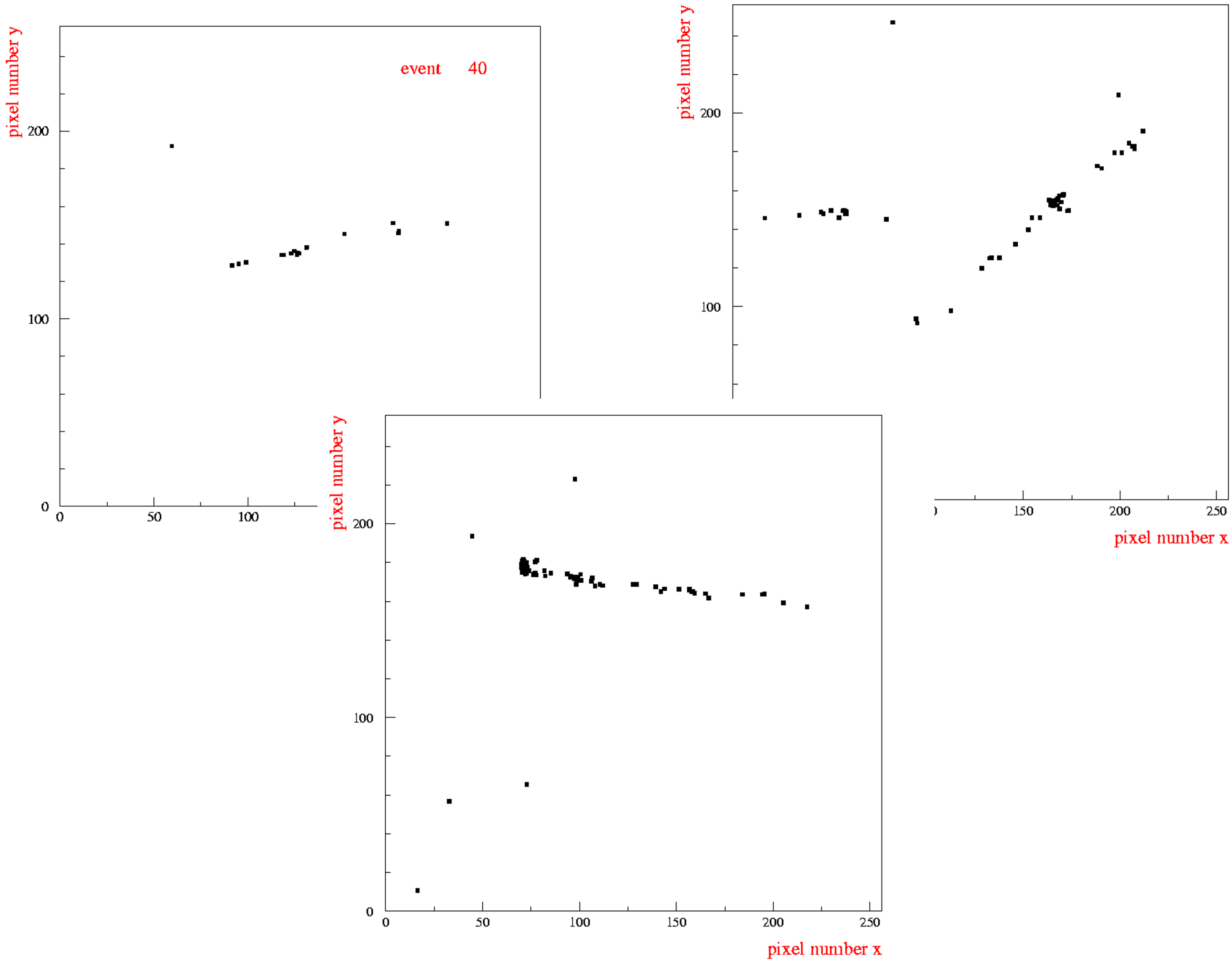


0
2.5
5
7.5
10
0
100
200
300
Projected lengths (pixels)
0
10
20
0.5
0.6
0.7
0.8
0.9
1
Fitted e- per mm
0
5
10
15
0
2
4
6
8
Fitted e- per mm
0
10
20
30
0
1
2
3
Fitted clusters per mm

Efficiency



- select tracks whose projection onto the sensitive pixel plane does not cross the boundary of this plane (to avoid ambiguities)
- track 3D length $L = \sqrt{(D^2+H^2)}$
- count number of charge clusters N: N/L gives information on number of primary electrons per unit length detected P_{Det}
- comparison with number of electrons released by a MIP in our gas mixture as given by literature (P_{Calc}) gives information about detection efficiency: $\varepsilon = P_{Det}/P_{Calc}$ > **90%** (He based gas mixt.)


event 40
pixel number y
pixel number x
0
50
100
150
200
250